

# **SWIR SKY GLOW IMAGING FOR DETECTION OF TURBULENCE IN THE UPPER ATMOSPHERE: POSTPRINT**

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**1 January 2010**

**Technical Report**

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 01-01-2010		2. REPORT TYPE Technical Paper		3. DATES COVERED (From - To) Mar 1, 2001- Jan 1, 2010	
4. TITLE AND SUBTITLE  SWIR Sky Glow Imaging for Detection of Turbulence in the Upper Atmosphere: Postprint				5a. CONTRACT NUMBER F29601-01-D-0051 TO 2 DF297490	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 63605F	
6. AUTHOR(S) David Dayton*, Rudy Nolasco*, Jeff Allen*, Mike Myers, John Gonglewski, Gregory Fertig, Dennis Burns**, Ishan Mons**				5d. PROJECT NUMBER 4296	
				5e. TASK NUMBER BV	
				5f. WORK UNIT NUMBER 40	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) *Applied Technology Associates 1300 Britt SE, Albuquerque NM 87123				**Textron Defense Systems Kauai 9565 Kaunualii Hwy, Waimea, HI	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Air Force Research Laboratory 3550 Aberdeen Ave SE Kirtland AFB NM 87117-5776				10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/RDSEA	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RD-PS-TP-2010-1015	
12. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release					
13. SUPPLEMENTARY NOTES Accepted for publication at the SPIE Optics and Photonics Symposium; Advanced Wavefront Control VIII; San Diego, CA; August 5, 2010. 377ABW-2010-0888; May 21, 2010. "Government Purpose Rights"					
14. ABSTRACT IT IS WELL KNOWN THAT LUMINANCE FROM PHOTO-CHEMICAL REACTIONS OF HYDROXYL IONS IN THE UPPER ATMOSPHERE (-85 KM ALTITUDE) PRODUCES A SIGNIFICANT AMOUNT OF NIGHT TIME RADIATION IN THE SHORT WAVE INFRA-RED (SWIR) BAND BETWEEN 0.9 AND 1.7 UM WAVE LENGTH. THIS HAS BEEN DEMONSTRATED AS AN EFFECTIVE ILLUMINATION SOURCE FOR NIGHT TIME IMAGING APPLICATIONS. IT ADDITION IT HAS BEEN SHOWN THAT OBSERVATION OF THE SPATIAL AND TEMPORAL VARIATIONS OF THE ILLUMINATION CAN BE USED CHARACTERIZE ATMOSPHERIC TIDAL WAVE ACTIONS ON THE SKY GLOW REGION. THESE SPATIO-TEMPORAL VARIATIONS MANIFEST THEMSELVES AS TRAVELING WAVE PATTERNS WHOSE PERIOD AND VELOCITY INSTABILITIES. GROUND TO SPACE OBSERVATION SYSTEMS ESPECIALLY THOSE EMPLOYING ADAPTIVE OPTICS ARE ADVERSELY AFFECTED BY HIGH ALTITUDE TURBULENCE AND WINDS. IN THIS PAPER WE PROPOSE THE USE OF SKY GLOW OBSERVATIONS TO PREDICT AND CHARACTERIZE IMAGE SYSTEM DEGRADATION DUE TO UPPER ATMOSPHERE TURBULENCE.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  SAR	18. NUMBER OF PAGES  10	19a. NAME OF RESPONSIBLE PERSON John Gonglewski
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) 505-846-4405

Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std. Z39.18

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# SWIR Sky Glow Imaging for Detection of Turbulence in the Upper Atmosphere

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## Abstract

It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band between 0.9 and 1.7  $\mu\text{m}$  wave length. This has been demonstrated as an effective illumination source for night time imaging applications. In addition it has been shown that observation of the spatial and temporal variations of the illumination can be used to characterize atmospheric tidal wave actions in the sky glow region. These spatio-temporal variations manifest themselves as traveling wave patterns whose period and velocity are related to the wind velocity at 85 km as well as the turbulence induced by atmospheric vertical instabilities. Ground to space observation systems especially those employing adaptive optics are adversely affected by high altitude turbulence and winds. In this paper we propose the use of sky glow observations to predict and characterize image system degradation due to upper atmosphere turbulence.

## 1.0 INTRODUCTION

Sky glow from chemical luminescence in the upper atmosphere has been observed at a number of different wavelengths [1-3]. In the short wave infra-red (SWIR) between 1.0  $\mu\text{m}$  and 1.7  $\mu\text{m}$ , it is due to emissions from hydroxyl radicals transitioning from excited rotational and translational states to lower energy states and emitting a SWIR photon in the process.

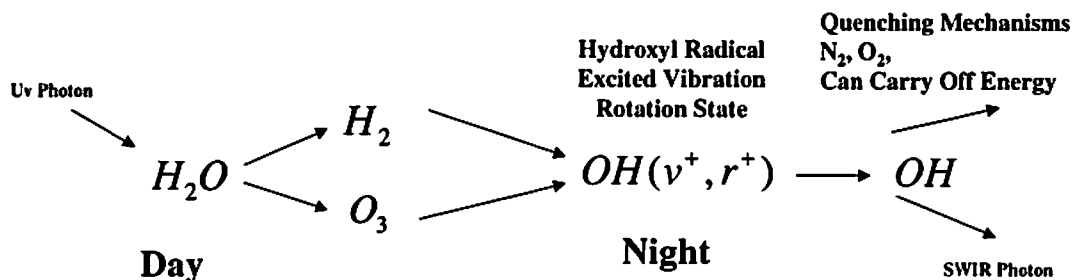


Figure 1.1 Synoptic Sketch of the Air Glow Process in the Infra-Red.

Figure 1.1 is a synoptic sketch of the air glow process for production of illumination in the SWIR band. Although the chemical reactions are very complicated, the overall effects can be summarized as follows. During the day, UV photons strike water molecules and initiate the production of hydrogen and ozone. At night, the hydrogen and ozone recombine and form the excited hydroxyl radicals with elevated vibration and rotational energy states. The molecules then transition to a lower energy state emitting a SWIR photon. The process can be quenched by other molecules, among them  $\text{O}_2$  and  $\text{N}_2$ , which carry off the energy.

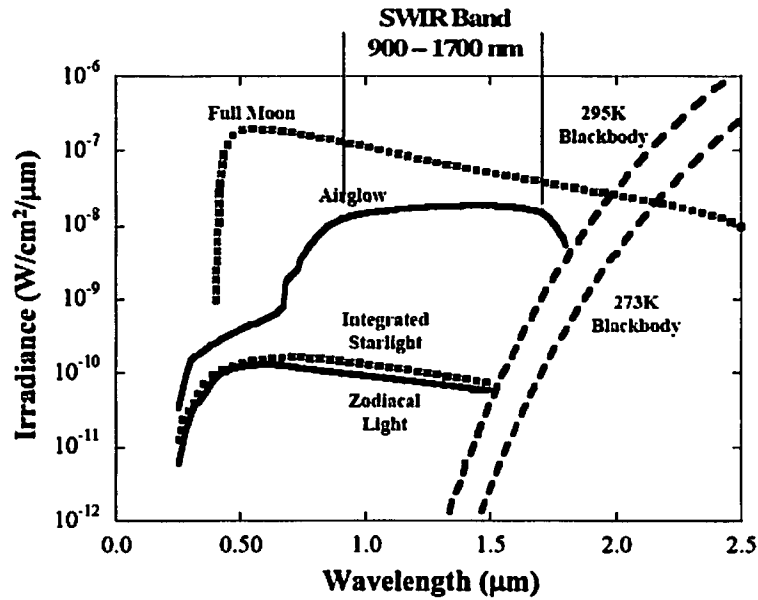


Figure 1.2 Night Time Illumination Sources

Figure 1.2 shows sources of night time illumination that can be used for imaging [1]. Of course the brightest source is the moon. When the moon is not out, or is obscured by clouds, figure 1.2 shows that sky glow provides a significant source much greater than thermal radiation in the SWIR band.

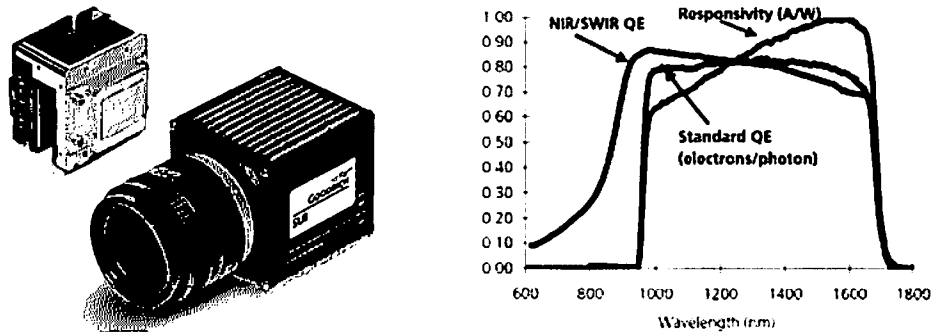


Figure 1.3 Sensors Unlimited SWIR Camera Used to Make SWIR Measurements of Sky Glow.

The SWIR camera used for the measurements was a Sensors Unlimited model 320KTX with 320x240x40  $\mu\text{m}$  pixels. The camera has quantum efficiency above 60 % from 900 nm to 1700 nm as shown in the curve in figure 1.3. The effective read noise of the camera was about 50 equivalent detected photons per pixel.

SWIR image measurements shown in the subsequent sections were made using an F/1.4 50 mm focal length camera lens. With SWIR air glow irradiance levels, optics faster than F/2.5 are typically required for passive night glow imaging in order to concentrate enough light onto the detector array.

In order to make comparisons, two visible cameras were used in conjunction with the SWIR, an intensified CCD camera operated at 30 Hz, and a low noise CCD camera with 1 second exposures.

## 2.0 Gravity Wave Formation

Gravity wave formation is a function of the wind shear and the atmospheric vertical thermal stability. We want to consider the formation of gravity waves in the upper atmosphere in the region of the sky glow. Note that atmospheric gravity waves as described here should not be confused with relativistic gravity waves, which are a much different phenomena.

Several relevant equations follow.

Vertical Shear of Horizontal Wind

$$S = \left[ \left( \frac{du}{dz} \right)^2 + \left( \frac{dv}{dz} \right)^2 \right]^{0.5} \quad (2.1)$$

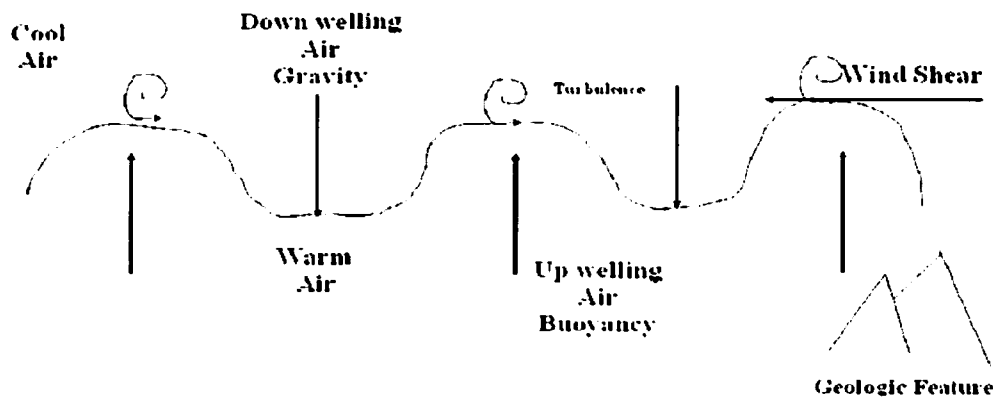
where  $u$  and  $v$  are the two orthogonal components of the horizontal wind velocity.

Bunt-Vaisala Frequency Squared

$$N^2 = \frac{g}{T} \left[ \left( \frac{dT}{dz} \right) - \left( \frac{dT_{ADA}}{dz} \right) \right] \quad (2.2)$$

$$Ri = \frac{N^2}{S^2} \quad (2.3)$$

A large Richardson number implies atmospheric stratification, while a small number implies turbulent wave formation.



**Figure 2.1** Wind Shear Initiates Gravity Waves.

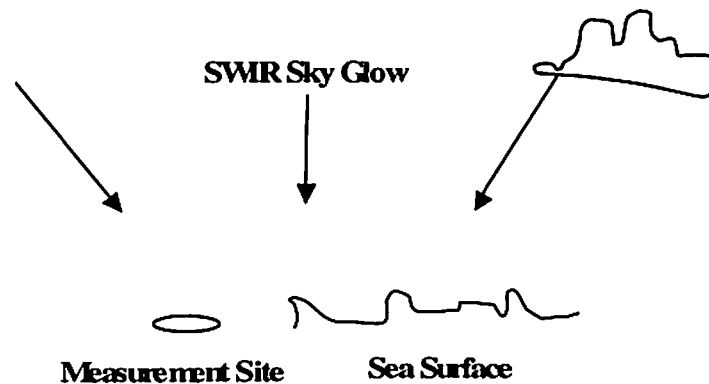
Observed gravity waves can be related back to the velocity, direction, and shear of upper atmospheric winds at approximately 80 Km.

## 3.0 MEASUREMENTS

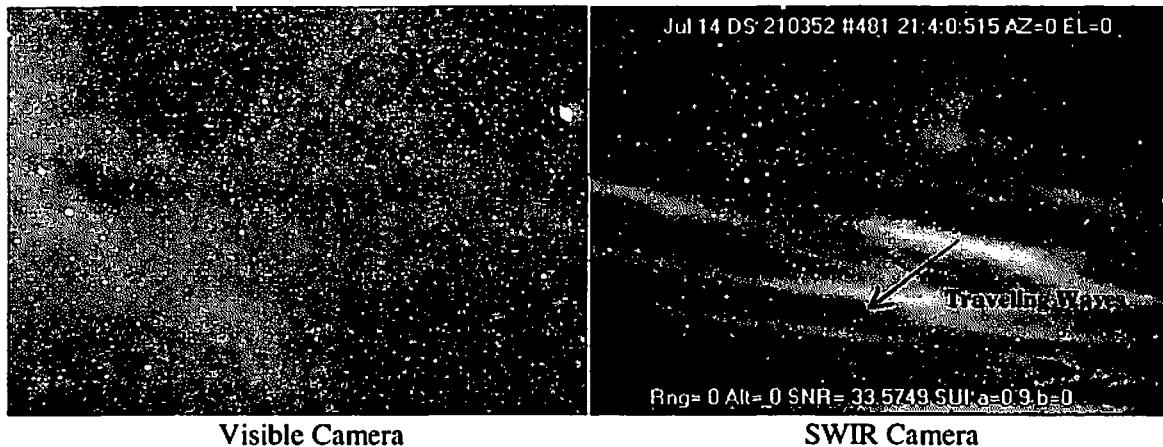
Image measurements of sky glow wave patterns were primarily carried out at a rural site on the west coast of the Hawaiian island of Kauai. The Kauai site has very little ambient illumination other than direct and scattered moonlight.

### 3.1 KAUAI SITE

We next consider the Kauai measurement site. This site is located on the west coast of the island with very little in the way of ambient street or housing light pollution. When the moon is not out, the only source of illumination is from the sky glow.



**Figure 3.1 Kauai Rural Measurement Site**



**Figure 3.2 Visible and SWIR images from Kauai Site Showing Sky Glow Traveling Wave Patterns.**

Figure 3.2 shows some interesting intense striations in the sky glow radiance from the Kauai site. The irradiance from these striations was about  $4.1 \times 10^{-8}$  Watts per  $\text{cm}^2$ .

If we consider the direction and speed of the traveling waves we can estimate the speed and direction of the winds aloft. In addition if we consider the peak to valley modulation of the waves we can estimate the wind shear at altitude.





Visible Camera

SWIR Camera

**Figure 3.3 Sky Glow Measurements showing low Contrast Wave Pattern.**

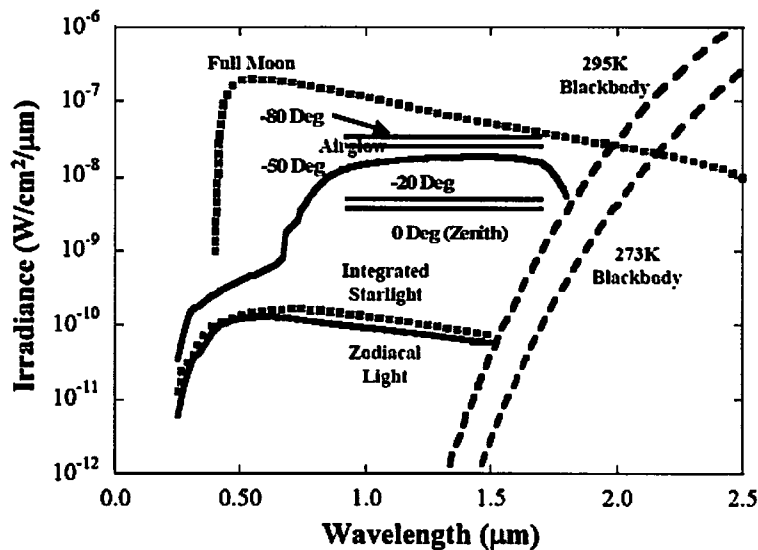
Figure 3.3 shows sky glow wave pattern with a lower contrast than that shown in figure 3.2. This indicates that the vertical instability described in section 2 is not as intense as during the time period shown in figure 3.2.

Zenith Angle	SWIR SKY Glow Irradiance Kauai
-85	$3.9 \times 10^{-8} \text{ W/cm}^2$
-80	$2.3 \times 10^{-8} \text{ W/cm}^2$
-75	$2.5 \times 10^{-8} \text{ W/cm}^2$
-65	$1.3 \times 10^{-8} \text{ W/cm}^2$
-35	$4.6 \times 10^{-9} \text{ W/cm}^2$
-20	$4.5 \times 10^{-9} \text{ W/cm}^2$
0	$8.0 \times 10^{-9} \text{ W/cm}^2$

**Table 2** Sky Glow Radiance Measurements as a Function of Zenith Angle Kauai Site.

#### 4.0 CONCLUSIONS

Chemical luminescence from excited hydroxyl radicals in the upper atmosphere at about 80 km provides a natural illumination source for night time imaging in the SWIR band between 1.0 and 1.7  $\mu\text{m}$ . A series of image measurements have been made of sky glow radiation at two measurement sites, one outside of Albuquerque, and a second on the west coast of Kauai, Hawaii. The irradiance levels measured were consistent with published levels as shown in figure 3.1



**Figure 4.1** Night Time Illumination Sources With Sky Glow Measurements Superposed.

Section 2 described the formation of gravity waves in the upper atmosphere caused by vertical instabilities and wind shear. In this paper we propose the use of visual measurements of sky glow wave formations, induced by the gravity waves, to estimate the turbulence in the upper atmosphere. This may be significant for predicting the performance of adaptive optics systems.

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